Lateral Zonation of Trees along a Small Ohio Stream[1]

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ABSTRACT. **Riparian-vegetation patterns along a small stream in Ohio were examined with multivariate and graphical analyses. The study focused on elevational differences in larger tree species (≥10 cm DBH = diameter at breast height) on a floodplain bench, floodplain slope, and upland terrace. The three habitat zones showed differences in floral assemblages related to the flooding tolerance of tree species, the floodplain bench showing ash-maple dominance and the other habitats yielding maple-beech-oak dominance. The floral differences were likely attributable to natural and human impacts, particularly stream flooding and possibly past logging. The results and a literature review suggest that hydrologic disturbances (for example, flooding) create predictable, parallel patterns in floral assemblages along a lateral (stream-edge to upland) gradient. Riparian assessments in the lateral dimension can provide information to predict the effects of anthropogenic instream-flow alterations on riparian ecosystems, including small tributaries.**

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"The oaks are just too greedy, we'll make them give us more light" (quote from the maples in the rock song "The Trees," by Rush).

INTRODUCTION

The species and growth-form composition of riparian vegetation in mesic regions of North America is greatly affected by stream-flow regimen (Gill 1970, Broadfoot and Williston 1973), including minimum and maximum flows and fluctuations in discharge (Rood and Mahoney 1990, Vadas and Weigmann 1993, Auble and others 1994, Johnson 1994). Indeed, natural flood disturbances enhance plant productivity and biodiversity in riparian ecosystems, with resulting benefits to fish and wildlife resources (Gregory and others 1991, Naiman and others 1993, Decamps and Tabachi 1994). In the north-central US, abiotic disturbances caused by floods, drought, scouring by ice, and river meandering often enhance tree-species and forest diversity by setting back floral succession to earlier seral stages, that is, toward r-selected, woody species that are adapted to low nutrient and high light levels (Johnson and others 1976; Johnson 1992, 1994). Differences in stream hydrology along lateral (stream-edge to upland) and longitudinal (up- to downstream) gradients have been examined by ecohydrologists, who attempt to correlate hydrologic and floral patterns in stream valleys (Higler 1993).

Much ecohydrologic work has been done to document the distinct lateral zonation of plant species on benches (formerly called "terraces") that run parallel to streams in the eastern US (Hupp 1988, Gosselink and others 1990) and western US (Fonda 1974, Karp and Mathews 1988, Brinson 1990). In particular, a higher proportion of large, woody, long-lived, shade-tolerant, and/or water-intolerant plants (that is, K-strategists) is seen at higher elevations. Grasses and other herbs dominate the low bench (depositional bar), woody and herbaceous shrubs characterize the second bench (active-channel shelf), woody shrubs and mesic trees dominate the third bench and slope (floodplain and transition), and drier-adapted trees typify the upland bench (terrace) and slope (toeslope and hillslope). Essentially, the first two benches characterize the stream bank and isles (lower-riparian zone), where inundation is frequent (≥5% of the time in Virginia) (Hupp and Osterkamp 1985). In contrast, the third bench is in the upper-riparian zone and the upland bench is above the present highwater mark, with respective flood intervals of 1-3 years and >3 years in Virginia (Hupp and Osterkamp 1985).

Typical floral genera characterize lotic benches in North America. In much of the northeastern US, important riparian shrubs include willow (*Salix*), alder (*Alnus*), and *Viburnum*, whereas floodplain trees include ash (*Fraxinus*), maple (*Acer*), cottonwood (*Populus*), birch (*Betula*), and elm (*Ulmus*) (Vankat 1979, Hupp 1988, Brinson 1990). Upland trees include beech-maple (*Fagus-Acer*) and oak-hickory (*Quercus-Carya*) associations (assemblages) in wetter and drier areas, respectively.

In the present paper, multivariate and graphical analyses are used to examine riparian-floral patterns along one side of a small stream in Ohio. The rapid-bioassessment study focuses on elevational differences in larger tree species on a floodplain bench (floodplain), floodplain slope (slope), and upland terrace (upland) in relation to stream hydrology (Fig. 1). Drier-adapted species were expected to be more common farther upslope, away from the stream. Tree composition on the slope was expected to be intermediate to that on the floodplain and upland, assuming that floral change was continuous rather than discrete along the lateral gradient.

METHODS AND MATERIALS

Study Watershed

The study site is in Ohio Wesleyan University's Bohannan Scientific Preserve, just north of Kilbourne on the southeastern shore of Alum Creek (Brown township in

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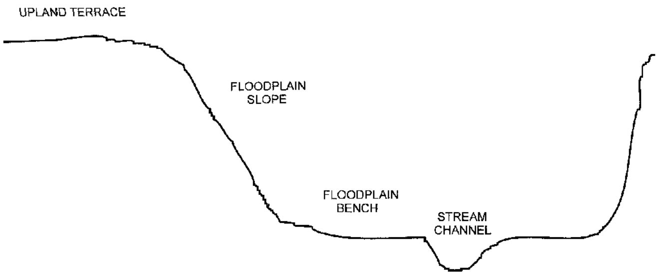

FIGURE 1. Habitat types along a lateral (elevation) gradient for the Ohio study stream.

Delaware and Morrow counties, 40°21' N and 82°55' W). This mature, second-growth forest tract is 85 to 135 years old (Wallace 1982) and has well to moderately drained soils developed on thin glacial till over Ohio shale bedrock. The preserve is within Ohio's mesic, beech-maple forest region (Vankat 1979). Deciduous trees, namely beech, maple, oak, hickory, elm, ash, and sycamore (see Table 1 for taxa) are prevalent in the preserve, the latter primarily on the Alum Creek floodplain. Evidence of past logging includes beech and maple root-sprouts and an extensive, second-growth understory of herbs and shrubs (Wallace 1982, personal observation). Agriculture is the dominant land use on fields adjacent to the preserve.

We undertook sampling in the southeastern corner of the preserve, on the northeastern side of a second-order, meandering tributary of Alum Creek (as determined from a 1:24,000 topographical map). The unnamed stream is intermittent (occasionally with zero flow) and 1.9 km long below the confluence of its two tributaries, with an average gradient of 4.8 m/km and exposure of Ohio shale along the slope and bank. The sample site was near the confluence in Morrow County, which ranged in elevation from 283 to 293 m along a habitat gradient from floodplain to slope to upland Prominent herbs on the upland-forest floor were those typical of eastern beech-maple forests (compare Vankat 1979), whereas may-apple (*Podophyllum peltatum*) was most abundant on the floodplain. Blue-beech (*Carpinus caroliniana*), hop-hornbeam (ironwood), and sugar-maple saplings dominated the upland subcanopy, whereas saplings of Ohio buckeye and hop hornbeam characterized the floodplain subcanopy (see Table 1 for taxa)

Field Work

Sampling was undertaken from late March to late May in 1983 on two adjacent bends in the midreach of the study creek (compare Vadas 1984). We used the point-quarter method, a plotless technique that is efficient for sampling tree assemblages (Cox 1980, Brower and others 1990). Three transects were laid out from the upland to the stream bank, perpendicular to the stream; the first upland point was adjacent to the floodplain of a smaller tributary of Alum Creek. Each transect was 160 m long with stakes marking sampling points every 20 m,

TABLE 1

Abundance and size data for trees in three habitat types along an Ohio stream.

Tree species Common, scientific, & abbreviated name		Floodplain N	Floodplain A	Floodplain D	Slope N	Slope A	Slope D	Upland N	Upland A	Upland D	TOL
American beech (*Fagus grandifolia*)	ABE	5	8	29.5	22	21	36	23	27	35	IN
Red oak (*Quercus rubra*)	ROA	0	0	—	4	13	67	0	0	—	IN
White oak (*Quercus alba*)	WOA	0	0	—	11	29	59	5	5	35	IN
Sugar maple (*Acer saccharum*)	SMA	22	12	16	33	28	33	46	42	31	IT
Red maple (*Acer rubrum*)	RMA	5	12	33.5	6	2	20	2	1	27	TO
Green ash (*Fraxinus pennsylvania subintegerrima*)	GAS	18	8	15	10	3	21	10	12	36	VT
White ash (*Fraxinus a. americana*)	WAS	29	40	23.5	6	3	24	0	0	—	VT
Shagbark hickory (*Carya ovata*)	SHI	0	0	—	0	0	—	7	8	34	IN
Wild black cherry (*Prunus serotina*)	WBC	0	0	—	8	2	17	0	0	—	IN
Hop hornbeam (*Ostrya virginiana*)	HHO	8	4	15	0	0	—	0	0	—	IN
Ohio buckeye (*Aesculus glabra*)	OBU	5	8	30	0	0	—	2	+	11	IT
Honey-locust (*Gleditsia tricanthos*)	HLO	4	7	33	0	0	—	0	0	—	IT
Sycamore (*Platanus occidentalis*)	SYC	0	0	—	0	0	—	2	4	49	TO
American elm (*Ulmus americana*)	AEL	4	1	10	0	0	—	2	1	26	TO
Summary data	—	52	—	21	32	—	33	24	—	33	—
Simpson-Levins diversity index	—	5.5	4.6	—	5.2	4.4	—	3.5	3.7	—	—

N = % numerical abundance, A = % areal abundance, and + indicates <0.5%.
Summary data include total number of trees and mean diameter (D) across species.
Classifications of flooding tolerance (TOL) were based on Chapman and others (1982): VT = very tolerant, TO = tolerant, IT = intermediately tolerant, and IN = intolerant.
Species names follow Weishaupt (1971) and Vankat (1979). See the text for an explanation of calculations.

yielding 9 points per transect (total = 27 points). The transects were oriented NE-SW and were approximately 30 m apart. This spacing prevented the same tree from being sampled more than once, and provided several stakes per transect for each habitat type. Four trees were sampled per point yielding a total of 52, 32, and 24 trees for upland, slope, and floodplain habitats, respectively.

At each stake, we assessed the nearest tree in each of the four quadrants. Measurements included distance of the tree to the stake (at 0.6 m height), tree circumference at 1.4 m height (to calculate diameter at breast height = DBH), and presence/absence of lianas on the tree trunk (principally poison ivy [*Rhus radicans*] and wild, riverside grape [*Vitis riparia*]). The minimum DBH for trees was 10 cm, such that only overstory trees were sampled.

Data Analysis

Although the point-quarter method can provide frequency, density, dominance (basal-area), and dispersion estimates for each tree species, the method is most accurate when tree distributions are random and sample sizes are large (Cox 1980, Brower and others 1990). We focused on the relative numerical and areal abundance of trees, variables that were similar in form (Cox 1980, Brower and others 1990) and value (Vadas 1984) to relative density and dominance. Tree density (TD) was factored into these variables by calculating TD = 20 - DIST. Percent numerical abundance across all species was calculated by summing TD for each tree species. Percent areal abundance across all species was calculated by summing the product of TD and DBH2 for each tree species.

We used varimax-factor analysis (PROC FACTOR in SAS [1985]) and the Simpson-Levins diversity index (compare Vadas 1992) and graphical analyses of common tree species and flooding-tolerance guilds to examine vegetation patterns among habitat samples. There were 14 observations (tree species) and 6 variables, the latter including numerical and areal abundances of trees in floodplain, slope, and upland habitats. This allowed two floral comparisons, between abundance parameters (within habitat types) and among elevation zones, to assess whether change in tree-species composition was continuous along the lateral gradient. Habitats with floral compositions that were (1) highly similar would show their highest loadings on the same factor axis, (2) moderately similar would show high loadings on the same factor axis but their highest loadings would be on different axes, (3) somewhat dissimilar would show high loadings on different axes, and (4) more dissimilar would show high loadings on the same factor axis but the loadings would be of opposite sign (positive versus negative). Tree species were classified into one of four flooding-tolerance guilds based on the classifications of Chapman and others (1982), to test the hypothesis that tolerant species are relatively more abundant closer to the stream; the guilds included "very tolerant," "tolerant," "intermediately tolerant," and "intolerant."

RESULTS

There were four univariate patterns of interest. First, poison ivy was more common on floodplain trees than on trees in slope and upland habitats (Appendix 1); respective frequencies were 54%, 12.5%, and 12%. Second, trees were generally larger on the slope and upland than on the floodplain (Table 1). Third, common tree species (that is, those with numerical and/or areal abundance $\geq$10% in at least one habitat type) generally showed continuous variation in abundance along the lateral gradient (Fig. 2). Two species (American beech and sugar maple) were most abundant in the upland and least abundant on the floodplain, two species (white and red oak) were mostly found on the slope, two species (red maple and white ash) were most abundant on the floodplain and least abundant in the upland, and one species (green ash) was ubiquitous across the three habitat types but least abundant on the slope. Fourth, tree species tolerant to flooding were relatively more abundant closer to the stream (Fig. 3). Very tolerant species were dominant and intermediately tolerant taxa were subdominant on the floodplain, whereas intermediately tolerant and intolerant species dominated the slope and upland habitats.

Table 1 and multivariate (factor) analysis across tree species further suggest that floodplain and upland vegetation were distinct and the slope flora was more similar to upland vegetation. The floral samples each showed very high loadings on a single factor axes (FA), such that there were three important axes. FA #1 was characterized by both upland samples and numerical data for the slope, because of dominance by sugar maple and subdominance by American beech, green ash, and white oak. The upland flora was less diverse because of greater sugar-maple prevalence. FA #2 consisted of both floodplain samples, because of dominance by white ash and subdominance by green ash and both maple species. These samples were more diverse than the flora of higher elevations. FA #3 was characterized by areal data for the slope, because of dominance by two species (sugar maple and white oak) and subdominance by American beech and red oak. Numerical and areal data for the

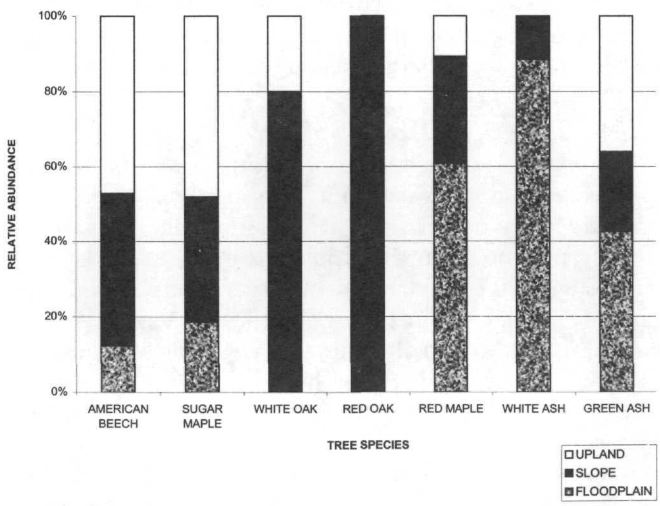

FIGURE 2. Relative abundance of common tree species across the three elevation zones, based on data in Table 1. Relative abundance, which added up to 100% for each tree species, was the average of percent numerical and areal abundances.

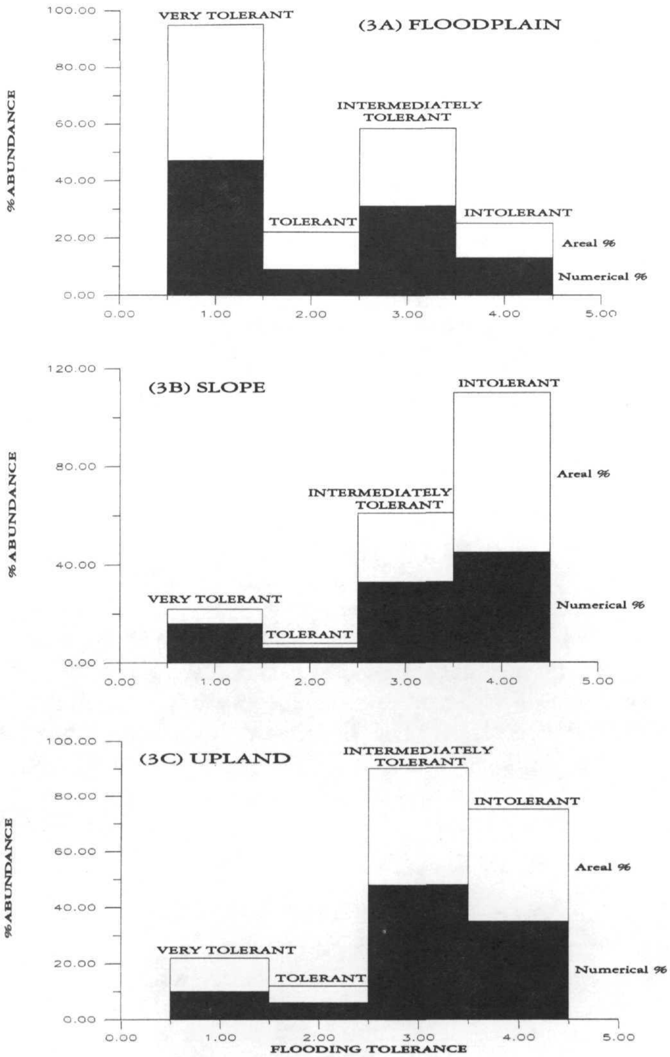

FIGURE 3. Percent composition by number (shaded) and area (white) for flooding-tolerance guilds in the three elevation zones, based on data in Table 1.

same habitat were concordant in two of three comparisons; the divergent areal data for the slope resulted from the presence of very large oaks in this habitat.

DISCUSSION

The results suggest five conclusions. First, the floodplain yielded a flood-tolerant, ash-maple assemblage, complete with poison ivy. This assemblage was only partially unique from the upland flora because green ash and several other tree species were found on more than one bench, as in other US studies (Vankat 1979, Brinson 1990). Given that upland vegetation generally dominates along smaller, headwater streams that rarely flood their banks, lack gully and bank stability, and/or are too slow-moving (average velocity <60 cm/s) for floodplain development (Thomson 1986, Hupp 1988, Brinson 1990, McLennan 1993), our study stream was apparently large enough to have hydrologic characteristics conducive to riparian vegetation. Second, higher-elevation habitats showed the expected beech-maple assemblage, including drier-adapted trees such as white oak (compare Vankat 1979, Hupp 1988, Brinson 1990). Beech had not yet attained dominance over sugar maple, in contrast to expectations for climax, old-growth forests in Ohio (Vankat 1979). Third, our study findings only partially corroborated those of Johnson and Bell (1976) for an Illinois watershed. Although both studies showed maples and oaks to be codominant on floodplain slopes, we did not find maples and oaks to be respectively most abundant on the floodplain and upland. The discrepancy may reflect the dominance of silver maple (*Acer saccharinum*) rather than sugar maple in the Illinois watershed, as well as past logging influences in the Ohio watershed. Sugar maple is generally more upland-oriented than silver and red maple (Gill 1970, Chapman and others 1982, Gosselink and others 1990, Gates and Giffen 1991). The higher percent abundances of large oaks and wild black cherry in the Ohio slope canopy suggests that this habitat was not heavily logged, since these trees were often selectively cut in beech-maple forests (Shelford 1963). Fourth, the smaller size of the Ohio floodplain trees is probably indicative of natural and human disturbances, namely flood damage and relatively intense logging. In contrast, Johnson and Bell (1976) found larger trees on an Illinois floodplain than at higher elevations, apparently because of faster regeneration after logging than in less-productive slope and upland habitats. And fifth, despite the potential logging impacts in our Ohio watershed, tree species were distributed according to their flooding tolerances.

Ecological studies along the lateral dimension should be of interest to watersheds managers for two reasons. First, researchers are emphasizing the importance of cumulative-impact, landscape-ecology analyses for protecting riparian ecosystems, because of the need to maintain coupling between streams and their floodplain and upland forests (Gosselink and Lee 1989, Gosselink and others 1990, Johnston 1994). For example, minimum woodland widths of 30 to 100 m are needed for maintenance of beech-maple forest ecosystems in riparian and upland habitats (Friesen 1994). Second, lateral assessments should allow researchers to determine which plant species and growth forms are most sensitive to human modification of instream-flow regimens. Reduced flooding of riparian habitat, which is caused by dams, intensive irrigation, and stream channelization, often cause floodplains to dry up and lose flood-adapted tree species in favor of floral taxa more typical of uplands (Bottorff 1974, Brinson 1990, Gosselink and others 1990, Vadas and Weigmann L993). Vegetation changes in the opposite direction are expected from prolonged flooding (as caused by reservoir inundation, levees, and flow enhancement), that is, increased dominance by aquatic, swamp, and/or short-lived terrestrial plants (Franz and Bazzaz 1977, Frederickson 1979, Nilsson and others 1991, Auble and others 1994) at the expense of floodplain hardwoods (Pearlstine and others 1985).

Clearly, riparian-floral assessments are important to minimize the extensive damage being done to riparian habitats and watershed ecosystems by various human activities (Chapman and others 1982, Brinson 1990).

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APPENDIX 1

Raw tree data for the three Ohio habitat types.

		Transect #1			Transect #2			Transect #3		
PT	QT	DIST	DBH	SPP	DIST	DBH	SPP	DIST	DBH	SPP
					Upland					
1	1	3.56	0.249	ABE	6.81	0.318	WOA	5.44	0.498	SMA
	2	3.58	0.264	SMA	2.11	0.267	GAS	5.00	0.165	SMA
	3	4.65	0.170	SMA	5.64	0.175	SMA	8.94	0.130	ABE
	4	9.42	0.432	SMA	5.64	0.526	ABE	10.64	0.323	SMA

Appendix 1 (Cont.)

		Transect #1			Transect #2			Transect #3		
PT	QT	DIST	DBH	SPP	DIST	DBH	SPP	DIST	DBH	SPP
2	1	7.85	0.368	WOA	11.02	0.226	SMA	8.03	0.574	SMA
	2	3.89	0.135	SMA	5.99	0.203	AEL	5.46	0.114	SMA
	3	1.30	0.376	SMA	5.99	0.500	ABE	5.05	0.493	SYC
	4	13.79	0.699	SMA	5.49	0.523	SMA	11.02	0.528	ABE*
3	1	4.29	0.157	ABE	10.80	0.406	GAS	3.45	0.274	RMA*
	2	3.12	0.356	ABE	4.98	0.132	ABE	2.97	0.112	OBU*
	3	4.83	0.295	SMA	1.93	0.246	SMA	3.63	0.564	GAS*
	4	2.82	0.213	SHI*	1.14	0.185	SMA	5.08	0.107	SMA
4	1	7.67	0.262	SHI	4.57	0.460	ABE	8.03	0.508	ABE
	2	4.88	0.351	ABE*	5.92	0.272	ABE	12.24	0.340	SMA
	3	8.69	0.437	SHI	7.29	0.465	SHI	9.40	0.551	SMA
	4	4.52	0.356	SMA	1.88	0.137	SMA	3.56	0.310	SMA
5A	1		—		—			5.61	0.254	GAS
	2		—		—			6.83	0.338	WOA
	3		—		—			8.10	0.292	SMA
	4		—		—			5.89	0.315	GAS
						Slope				
5B	1	5.59	0.170	WAS	4.60	0.147	SMA		—	
	2	1.17	0.157	WBC	1.27	0.185	WBC		—	
	3	5.87	0.643	WOA	11.43	0.318	GAS		—	
	4	10.31	0.218	ABE	3.56	0.147	GAS		—	
6	1	5.08	0.183	SMA	3.10	0.389	ABE	2.69	0.117	RMA
	2	6.45	0.516	ABE	4.14	0.411	ABE	0.20	0.673	ROA
	3	4.04	0.457	SMA	5.82	0.216	GAS	3.68	0.622	WOA
	4	6.98	0.577	WOA	3.58	0.361	ABE	9.50	0.536	WOA
7	1	5.61	0.305	WAS*	3.56	0.272	SMA	7.77	0.411	SMA
	2	9.12	0.287	RMA*	1.40	0.457	SMA	4.19	0.295	ABE
	3	8.92	0.142	GAS*	8.15	0.452	SMA	3.66	0.142	SMA
	4	1.85	0.335	SMA*	2.62	0.422	SMA	3.48	0.305	ABE
						Floodplain				
8	1	4.27	0.394	WAS*	4.17	0.340	WAS*	2.84	0.150	WAS
	2	8.23	0.191	WAS*	2.62	0.295	ABE*	5.44	0.257	SMA
	3	3.02	0.112	HHO	6.05	0.114	WAS*	2.31	0.193	SMA*
	4	7.72	0.130	GAS	1.09	0.175	GAS*	4.01	0.132	SMA
9	1	0.00	0.335	RMA	4.29	0.155	GAS	5.87	0.188	HHO*
	2	11.68	0.152	GAS*	5.77	0.112	WAS*	1.42	0.345	WAS
	3	6.98	0.328	HLO*	2.11	0.297	OBU	5.00	0.104	AEL*
	4	8.69	0.132	GAS	1.12	0.112	SMA	5.51	0.112	SMA*

Presence of poison ivy is indicated by *.
PT = point #, QT = quadrant #, DIST = stake-to-tree distance (m), DBH = diameter at breast height (m), and SPP = tree species.
See Table 1 for SPP abbreviations.